DIVISION S-7—FOREST AND RANGE SOILS

Retention of Soil Water Following Forest Cutting[1]

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ABSTRACT

Eucalyptus globulus (Labill.) forests in the Oakland-Berkeley hills, California, were clearcut in 1973-74 following severe damage from freezing in December 1972. The soil water regimes in clearcut and adjoining uncut areas, were compared during the two years following cutting.

During the wet winter season (Dec.-May), surface drying and evapotranspiration by annual grasses were the only losses in the clearcut; more soil water was retained in the clearcut due to lack of evapotranspiration by the forest trees.

Soil water rapidly decreased in both the clearcut and forest during the long, dry summer periods, and differences between the two areas widened. By midsummer soil matric suctions in the clearcut dropped below 15 bars (22.4% P_v, volumetric water content), and in the forest to below 70 bars (8.5% P_v). During the summer, P_v increased with profile depth in the clearcut, but in the forest, soil water was depleted uniformly with depth in the profile.

Although volumetric water contents of soil (P_v) were significantly different between clearcut and forest areas, rates of water loss (k) during summer were not clearly related to forest cover. In the clay-loam soil, k was dependent on the soil water storage at the beginning of the dry summer period, on the ability of trees in the uncut forest to withdraw water from parent material and from fractured bedrock in excess of that available in the soil profile, and on P_v which decreased during summer.

Additional Index Words: Eucalyptus globulus, California, hydrology, evapotranspiration, drying-rate constants, clearcutting.

VARIOUS *Eucalyptus* species were introduced to the USA in the 1850's for shade, windbreaks, and lumber. *Eucalyptus globulus* (Labill.), heralded as a potentially profitable lumber tree, was widely planted in southern California during this period and in the hills east of San Francisco Bay between 1910 and 1913. Although this use has not been realized in California (McIntire, 1973), dense stands of *E. globulus* became an integral component of the East Bay Regional Parks in the Berkeley-Oakland hills. These parks receive heavy recreational use, and it was not surprising that the unusually cold winter of 1972-73 (Monteverdi and Wood, 1973), which killed some trees and severely damaged the crowns of others, caused much concern amongst the public and park users. The controversy grew when much of the damaged forest was clearcut to reduce dangers of increased fire hazard due to rapid litter accumulation (Agee et al., 1973; Monteverdi, 1973), and to reduce dangers of falling branches injuring recreationists. During 1973 a 300-m fuelbreak, 19.5 km long, was cleared along the crest of the Berkeley hills. About 165 ha of the remaining damaged trees were clearcut in 1974. The area now resembles the same area at the turn of the century, prior to planting *E. globulus* (Fig. 1).

This study documents the effects of clearcutting on the soil water regime during the first wet season following cut-

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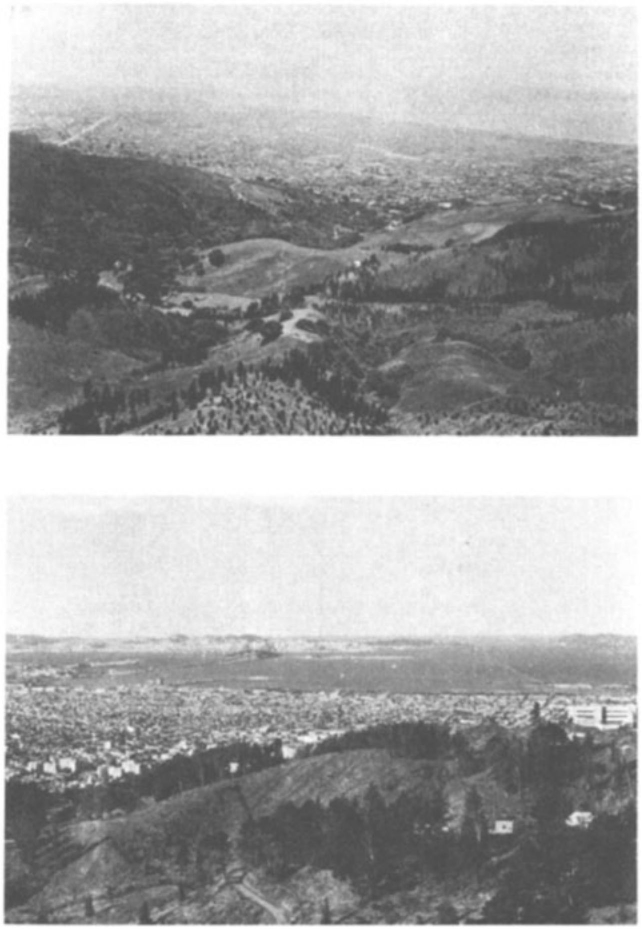

Fig. 1—Berkeley hills, California, before 1910, prior to planting *Eucalyptus globulus (upper)*, and in 1975 after clearcutting *E. globulus (lower)*.

ting, and during the two subsequent dry summer periods. Changes in movement and retention of nutrients following the clearcutting have also been studied.[3] Rates of soil-water depletion during summers were compared with those calculated by Zinke (1975), who proposed that such depletion rates are "constants" and can be used to characterize soil water use by different vegetation in climates where there is no summer precipitation.

Site Description

The study site was located in Tilden Regional Park, Contra Costa Co., California, in the hills about 2-km east of Berkeley (37°52'N, 122°15') on San Francisco Bay. The maritime climate has cool, wet winters and cool but dry summers with some fogs. Berkeley's mean annual temperature is 13.9°C, with means of 9.1°C in January and 16.4°C in July; mean annual precipitation is 56.80 cm, with means of 11.70 cm in January and 0.02 cm in July.

The study site had a 26% slope, an east-aspect and an elevation of 400 m. Natural vegetation occurring as a scattered understory in the *E. globulus* forest included *Baccharis pilularis, Rhus diversiloba, Rubus vitifolius, Umbellularia californía,* and a variety of annual grasses including *Avena fatua, Bromus mollis,* and *Lobium multiflorum* (McBride, 1974). Mean basal area was 48.5 m²/ha, and mean height of dominants in the uncut forest area was 46.3 m. The clearcut study area was cut in late spring, 1974.

[3]J. G. McColl, 1976. Soil solution changes following forest cutting. Agron. Abstr. p. 183–184.

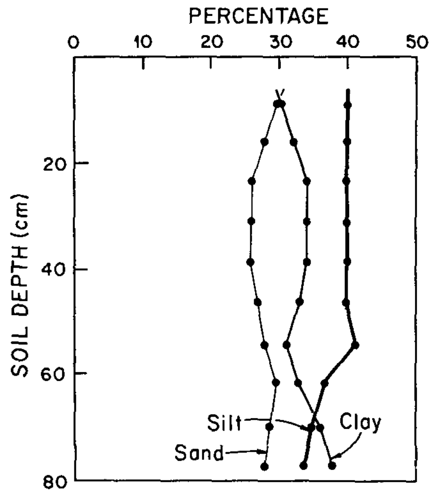

Fig. 2—Particle-size distribution with depth in the soil profile at the study site, Berkeley hills, California.

The soil, a Typic Argixeroll, clay loam developed from parent material of a basic-igneous metamorphosed-sediment complex (USDA, 1974). Particle-size distribution at the study site is fairly uniform with depth (Fig. 2). The A1 horizon is about 30-cm deep, reddish brown (5 YR 4/3 dry, 5 YR 3/3 moist), is hard, friable, sticky and plastic, with fine and very fine tubular and interstitial pores. The B2t, 30-65 cm, is reddish brown (5 YR 4/4 dry, 5 YR 3/4 moist) with medium, subangular blocky structure, hard, friable, sticky, and plastic with fine and very fine tubular and interstitial pores. Clay films line pores and ped surfaces. The B3t varies in depth from 65 to 92 cm, with similar properties to the B2t but with many thick clay films. The boundary between the B3t and the R horizon is fairly abrupt, but irregular and angular fragments of weather parent material are common.

METHODS

Effects of clearcutting were determined by comparison of an uncut area of *E. globulus* forest and an adjoining area that was clearcut in 1974.

Soil matric suctions were measured in triplicate on 23 occasions at both areas during the first wet season (Dec. 1974–May 1975) by porous-cup tensiometers (Richards, 1949), U.S. Salinity Laboratory Staff (1954) at depths of 15, 30, and 76 cm. During the two subsequent dry seasons, volumetric water contents (P_v) were measured in duplicate every 2 weeks in 1975 and monthly in 1976 by the neutron scattering method (Stone, et al., 1955). They were measured at four locations in both clearcut and forest areas, and at depths of 30, 45, 61, and 76 cm. Calibration curves for the neutron probe were verified by soil water contents determined gravimetrically, which were then multiplied by bulk density. The regression between P_v determined by both methods is: P (neutron probe) = $-1.04 + 1.01\,P_v$ (gravimetric) ($r^2 = 0.93$, $\alpha = 0.001$). The tensiometers and access tubes for the neutron probe were located along the same slope contour. Total soil water depletion rates during the dry seasons were calculated from P_v values for each depth and date.

Soil-water retention at matric suctions of 0.1, 0.3, and 15.0 bars were determined in duplicate for the $<$ 2-mm soil fraction in a pressure-plate apparatus (Richards, 1949, 1954). Toward the end of the dry season in 1976 soil matric suctions were determined with a psychrometer (Spanner, 1951; Monteith and Owen, 1958) on field samples collected and stored in plastic bags the previous day. Textural analyses were performed on duplicate samples of the $<$ 2-mm soil fraction using the hydrometer method (Bouyoucos, 1936, 1953).

Precipitation in the clearcut and throughfall in the *E. globulus* forest were measured in quadruplicate after each main storm event, with 20-cm diameter plastic funnels attached to collection

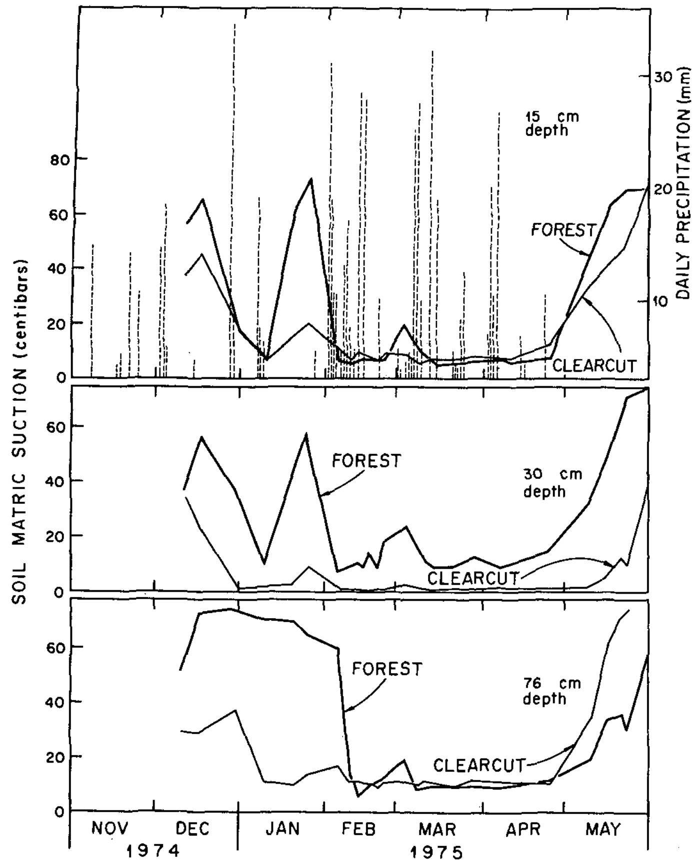

Fig. 3—Precipitation (bar diagram) and soil matric suction during the wet season, in clearcut and uncut *Eucalyptus globulus* forest, Berkeley hills, California. Daily precipitation was calculated from the regression equation relating precipitation between sampling dates in the clearcut to that recorded on the Berkeley campus (see text).

bottles placed at ground level. Daily precipitation at the study site was calculated from the regression equation relating precipitation in the clearcut with that measured at the nearest official National Weather Service station on the Berkeley campus of the University of California.

RESULTS AND DISCUSSION

Soil-Water Regime During the 1974–75 Wet Season

The regression of amount of precipitation in the clearcut *(C)* with that recorded on the Berkeley campus *(B)* yielded the following equation that was used to predict precipitation at the study site on a daily basis (Fig. 3, bar diagram): $C = 0.33 + 0.95\,B$ ($r^2 = 0.95$, $\alpha = 0.001$).

The regression of precipitation in the clearcut area *(C)* with throughfall in the *E. globulus* forest *(F)* yielded the following equation that indicates that 15% of precipitation was intercepted by the canopy and subsequently evaporated: $F = 0.27 + 0.85\,C$ ($r^2 = 0.90$, $\alpha = 0.001$). Similarly, Smith (1974) measured an average interception of 11% in a mature native stand of *E. rosii, E. maculosa,* and *E. dives,* and Attiwell (1966) measured average interceptions ranging from 26-29% in mature stands of *E. obliqua.*

Paired *t*-tests showed that the differences in mean soil matric suctions between clearcut and forest areas over the period Dec. 1974–May 1975 (Fig. 3) were significant at the 0.10 level of probability for the 15-cm depth, and at the 0.01 level for the 30- and 76-cm depths. At all depths there was greater retention of soil water in the clearcut.

At the 15- and 30-cm depths, differences in soil matric suctions between areas occurred between main precipitation events (Fig. 3). Evapotranspiration in the forest caused greater soil matric suctions than those at comparable times in the clearcut. At the 76-cm depth there were even greater differences between clearcut and forest areas; it was not until mid-February that soil matric suctions were < 20 centibars in both areas (Fig. 3).

These results are similar to those of Rogerson (1976) who found differences between soil water regimes of forest and clearcut areas in mixed hardwood forests in northern Kansas.

Table 1—Mean volumetric water content of soil (mean *Pv*) and total water storage in the profile to the 92-cm depth (Q_{sm}), at various matric suctions.

Matric suction, bars	Mean P_v	Q_{sm}, cm
0.1	40.4	36.28
0.3	34.4	31.12
15.0	22.4	20.28
70.0	8.5	7.80

Table 2—Drying rate constants *(k)* for the function $Q_{sm} = Q_{sm_0} \cdot e^{kt}$, for soils with various California vegetation covers: (A) hypothetical values typical of the Sierra Nevada (from Zinke, 1975), and (B) actual values for soils of clearcut and uncut *Eucalyptus globulus* forest, Berkeley hills (present study).

Vegetation cover	k
A) Barren ground	-0.0011
Annual grasses	-0.0036
Perennial grasses	-0.0030
Red fir	-0.0057
Chamise	-0.0118
Ponderosa pine	-0.0184
B) Clearcut, 1975	-0.0009
Clearcut, 1976	-0.0034
E. globulus forest, 1975	-0.0037
E. globulus forest, 1976	-0.0018

Soil-Water Regime During 1975 and 1976 Dry Seasons

There were significant differences (at the 0.05 level or better, as indicated by paired *t*-tests) in volumetric water contents (P_v) between areas for each depth and every measurement date (Fig. 4).

In the forest area there were no significant differences in P_v between depths (Fig. 4), indicating rapid and uniform depletion of soil water throughout the profile by the transpiring trees, which resulted in soil water contents far below the 15-bar level (Table 1). In contrast, there was a consistent increase in P_v with soil depth in the clearcut at all measurement times (Fig. 4). Here loss of soil water was limited to surface drying as annual grasses died before June, although water contents did reach the 15-bar level (Table 1).

Increases in P_v (Fig. 4) were due to precipitation starting on 6 Oct. 1975, and 14 Aug. 1976. In the clearcut area P_v was maintained following partial recharge, but in the forest, transpiration quickly reduced P_v to previous levels (Fig. 4).

Comparison of Drying Rates

Data of Fig. 4 were used to calculate the total soil water storage, Q_{sm} (in centimeters), in the soil profile (to 92 cm),

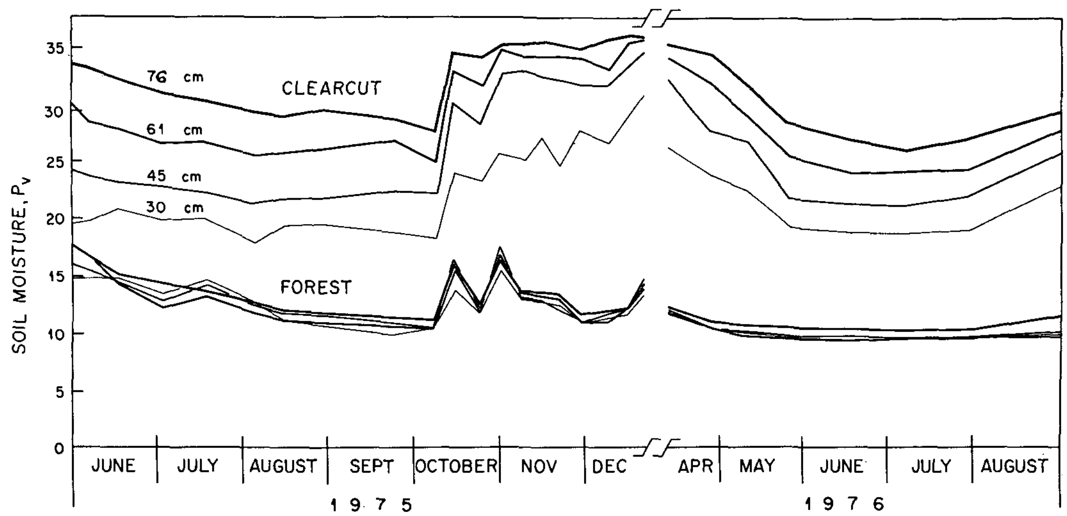

Fig. 4—Volumetric water content of soil (P_v), during two dry seasons in clearcut and uncut *Eucalyptus globulus* forest, Berkeley hills, California.

using only those data over drying periods uninterrupted by precipitation (i.e., June-Oct. 1975 and Apr.-Aug. 1976), and expressed as functions of time since the last precipitation event of spring, prior to summer drying (Fig. 5). The general equation is:

$$Q_{sm} = Q_{sm_0} \cdot e^{kt}$$

where Q_{sm} is the total soil water storage (cm) at time t, Q_{sm_0} is the total soil water storage (cm) when drying begins, t is the time (days) of drying since the last rain, and k is the drying-rate constant.

This semi logarithmic relationship has been used by others to describe soil water depletion curves in regions of long sumer drought (e.g., Knoerr[4], 1960; Zinke, 1959, 1975). Zinke (1975) proposed that values for the drying-rate constant, k, could be used to characterize soil-water use by various vegetation.

The following equations correspond to the linear relationships plotted in Fig. 5:

Clearcut, in 1975; $Q_{sm} = 23.39\ e^{-0.0009t}$ ($r^2 = 0.72$, $\alpha = 0.01$)

Clearcut, in 1976; $Q_{sm} = 27.02\ e^{-0.0034t}$ ($r^2 = 0.79$, $\alpha = 0.01$)

Forest, in 1975; $Q_{sm} = 16.43\ e^{-0.0037t}$ ($r^2 = 0.96$, $\alpha = 0.001$)

Forest, in 1976, $Q_{sm} = 10.27\ e^{-0.0018t}$ ($r^2 = 0.74$, $\alpha = 0.05$).

Drying rate constants (k) obtained here, and those proposed by Zinke (1975) for a variety of vegetation covers are listed in Table 2. The k values of the clearcut in 1975 and 1976 are almost identical to those of "barren ground" and "annual grasses" respectively. However, the k values for the clearcut and the *E. globulus* forest overlap, and considerable variation between years exists within areas (Table 2, and Fig. 5). This casts doubt on the usefulness of k to characterize soil-water depletion, particularly considering the drastic difference between the closed-canopy *E. globulus* forest with dominants over 43-m high, and the clearcut area which was devoid of vegetation other than annual grasses in spring.

A number of important factors contribute to changes in k for a given site in addition to vegetation cover. One of these is the initial soil-water storage at the beginning of the drying period (Q_{sm_0}). Based on detailed studies of soil water depletion by different vegetation growing in carefully controlled lysimeters filled with soil only, Zinke (1975) calculated k values for hypothetical situations in the field. He assumed that the soil was fully charged at the time of the last precipitation event prior to summer drying. In other words, Q_{sm_0} was assumed to be at field capacity. This was not the case in this present study for either the clearcut area or for the forest area in both 1975 and 1976 (Fig. 5 and Table 1). Clearly, k

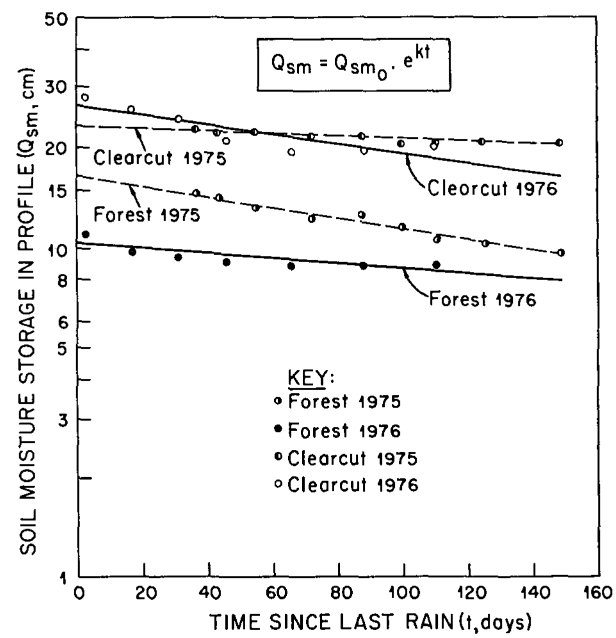

Fig. 5—Soil water storage (Q_{sm}) in the profile (to 92 cm) from the time (t) of the last storm preceeding the summer drying period, in clearcut and uncut *Eucalyptus globulus* forest, Berkeley hills, California.

[4]Knoerr, L. 1960. Exponential depletion of soil moisture by evapotranspiration at forested sites in the Sierra Nevada as related to available soil moisture and vapor pressure deficits. Ph.D. Thesis, Yale Univ., New Haven, CT. 177 p. (quoted by Zinke, 1975).

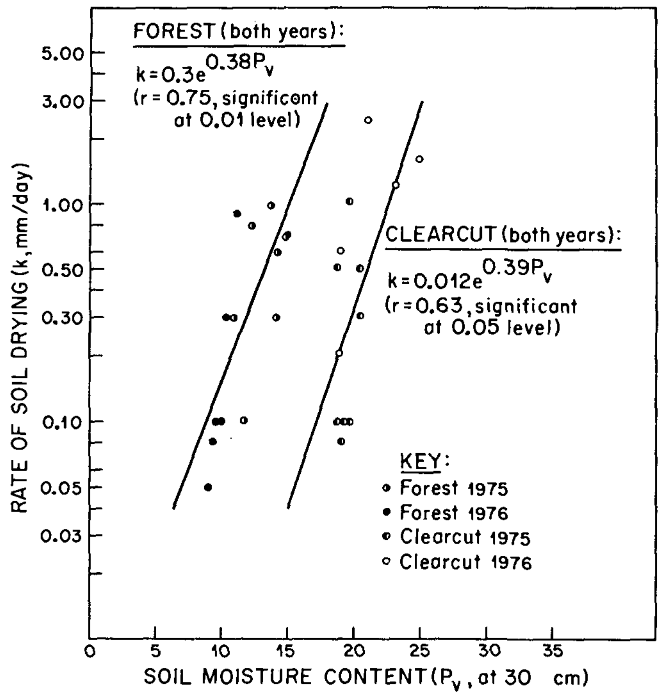

Fig. 6—Relationships between rate of soil water depletion from the total profile *(k)*, and volumetric water content of soil *(P_v)* at the 30-cm depth in clearcut and uncut *Eucalyptus globulus* forest, Berkeley hills, California.

values (the slopes of the lines in Fig. 5), were also determined by Q_{sm_0} under field conditions.

Rates of soil water depletion were also influenced by the withdrawal of water by roots that penetrated parent material and rock fractures containing water in excess of that in the soil profile, and also by decreasing soil water contents during the drying period (Fig. 6). These conditions are common for most field situations. Thus the use of k to distinguish between different soils and/or vegetation (Zinke 1975) has little practical value unless all important factors limiting soil water depletion are considered.

CONCLUSIONS

1) Clearcutting resulted in greater retention of soil water between precipitation events in the wet season and throughout the long dry seasons due to decreased evapotranspiration. This will probably result in decreased slope stability (Brown and Shue, 1975; Gray, 1970). Soil matric suctions exceeded 15 bars in the clearcut, and 70 bars in the forest during the dry seasons.

2) There were no clear differences between values of the drying-rate constant *(k)* for clearcut and forest areas. This was because roots in the uncut forest area withdrew water from parent material and fractures in bedrock as well as from the soil profile, because initial soil water storage (Q_{sm_0}) differed between areas, and because k decreased with volumetric soil-water content (P_v) during the drying period. The value of k to characterize soil water depletion by different vegetation as proposed by Zinke (1975) is probably limited to a few special cases, uncommon in real field conditions.

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